Preliminary development of polymer based filler materials for GFRP tubular connector

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ABSTRACT: New fillers confined with Glass Fiber Reinforced Polymer (GFRP) circular tubes provide a suitable structural member for a variety of applications including piles, columns and provide very high strength in compression. The filament architecture plays an important role in the properties of the tube to provide the confinement to the filler. Apart from providing confinement, GFRP tubes also serve as formwork and protect filler from deterioration. In this paper, a preliminary development of polymer based filler materials for GFRP tubular connector is discussed as a substitute of conventional concrete fillers. Sample trial mixes were considered based on several weight percentages of polymer resin, fly ash and sand. Material parameters such as compressive strength, stiffness, shrinkage and gel time were achieved from the experimental investigation. It has been found that most polymer based trial mixed fillers have high compressive strength and considerable plastic region with more than 10% strain. However, the behavior of fillers with GFRP confinement under different loading conditions is yet to be fully understood.

1 INTRODUCTION

Wood piles have been traditionally used in many bridges in Queensland, Australia for piers, especially when loose granular materials are present. Locally available wood piles provide a low-cost foundation system. Untreated wood piles are subjected to deterioration from marine borers, crustaceans, fungi and other sources. For this reason many wood piles have been treated in the past with preservatives, like creosote or chromated copper arsenate (CCA) (Lopez-Anido 2003). With time, preservatives are leached from the wood, and thus deterioration begins in treated wood piles similar to that of untreated wood piles.

When wood piles deteriorate, the conventional repair is to dismantle the pier, extract the deteriorated piles, drive new piles and rebuild the pier over the new piles. In addition, treated extracted piles may need special disposal. For some facilities, especially when road bridge sits on piers, extraction of all piles and driving of new piles can be difficult and costly. In these cases replacing deteriorated part with new pile becomes a viable alternative. Replacements are possible since the portion of the pile below the mudline is normally fully intact. The major deterioration occurs in the portion of the pile in the inter-tidal zone and the splash zone (above high-tide).

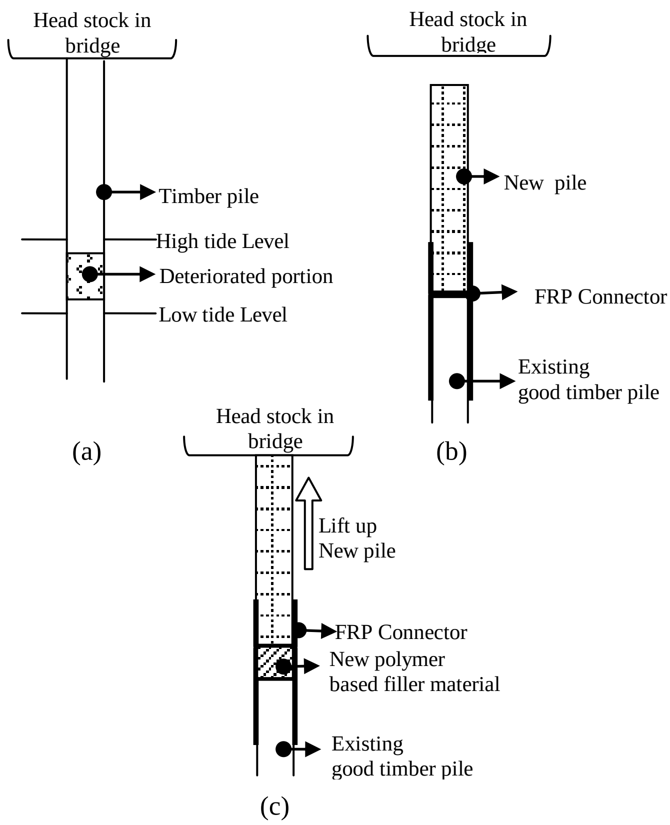


Figure 1. (a) General layout of the deteriorated timber pile, (b) Installing FRP connector and new pile in to the remaing non deteriorated timber pile, (c) Filling new polymer base filler material in to the connector.

The replacement system basically consists of new pile which was made out of any material like timber, FRP or concrete and GFRP tubular connector. The connector was used to join existing timber pile and new pile. To make easy constructability, first connector was inserted to existing timber stump (Figure 1(b)).Then, new pile was inserted to the connector and both lifted up, until attach to the head stock. After that, void in between connector and existing timber pile was filled with new filler to transfer the vertical load from the connector to the original stump (Figure 1(c)). Therefore development of this new polymer base filler was important and will be discussed in this paper.

GFRP connector was acted as a confinement for the filler. As per the Figure 1(c) this filler material used for filled in between connector and existing timber pile. This filler must have good workability, less curing time, fair compressive capacity and reasonable pumpability qualities. In past decade, most researches were conducted to study on behaviour of concrete wrapped with GFRP confinement. For the durability considerations, concrete was not suitable material for GFRP confinement. When FRP systems are used with concrete, whether internal or external reinforcing, the fibres and matrix will be exposed to the high alkaline environment present in the concrete. This environment is known to attack some glass in FRP composites (Christensen 1996). Katsuki and Uomoto tested glass, aramid, and carbon FRP exposed to NaOH solution (Katsuki 1995). Circular AFRP, CFRP and GFRP rods with 6 mm in diameter and 40 mm long were immersed in a solution of NaOH and then tested until a tensile failure occurred. The GFRP rods were subjected to a solution with half the concentration of NaOH because of poor resistance of glass fibres to alkali. The NaOH solutions were kept at a temperature of 40^{o}C. The rods were tested at 20^{o}C after exposure times of 7–120 days. It was found that the alkali penetrated the GFRP rods radially with time while the CFRP and AFRP rods had no penetration of alkali. In addition, tensile tests showed that only the GFRP rods lost strength with time after exposure to alkali. The area of the GFRP rods penetrated by alkali failed at a lower load than the areas not penetrated by the solution (Hamilton 2000).

Polymers are being increasingly used in civil-engineering applications as adhesives, modifiers, and matrix materials in concrete. As structural and repair materials, polymers and their composites must be able to withstand high stresses under extreme service conditions. Polymer Concrete (PC) is a composite material formed by combining a mineral aggregate such as sand and gravel with a polymerizing monomer (Vipulanandan 1993).

Because of low cost, the most widely used polymer-binders are based on unsaturated polyester polymer. In most applications, the polyester binder is a general purpose, unsaturated polyester prepolymer formulation. These formulations are available in the form of 60 to 80 percent solutions of the prepolymer in copolymerizable monomers such as styrene and styrene-methyl methacrylate. During hardening, the polyester prepolymer and the monomer react through their unsaturated groups (double bonds). The chemical reaction is called cross-linking, the production process associated with it is referred to as curing, and the resulting polymer binder is a thermosetting polymer.

Polyester PC has good mechanical strength, relatively good adhesion to other materials, and good chemical and freeze-thaw resistance. It has, however large setting and post-setting shrinkage (up to ten times greater than Portland cement concrete), a serious disadvantage in certain applications. As a result this preliminary filler material development polyester was used as a resin.

The work presented here covers preliminary development of polymer based filler material for the GFRP tubular connector.

2 EXPERIMENTAL PROGRAMME

2.1 *Mix proportions and materials*

In this development, sample trial mixes were considered based on several weight percentages of polyester resin, fly ash and sand given in Table 1. 40% to 60% (w/w) polyester resin content was used to achieve good workability and pumpability requirements.

Table 1. Mixing proportions

Sample Number	(Resin+Initiator)% -By total weight -(R)	Filler (%) Sand -(S)	Filler (%) Fly ash -(F)	Initiator(%)-Weight % of resin
1000	50	25	25	2.5
1001	50	20	30	2.5
1002	50	30	20	2.5
1003	50	50	-	2.5
1004	60	40	-	2.5
1005	40	60	-	2.5
1006	56	-	44	2.5
1007	65	-	35	2.5
1008	45	-	55	2.5

The following constituent materials were used in the production of the polymer base filler.

Polyester Resin- Medium reactivity, rigid orthophthalic polyester resin was used. Compaired with other polyester families orthophthalic polyester have good chemical resistance and processibility (Dudgeon,1987).

Initiator- Methyl ethyl ketone peroxide(MEK) in dimethyl phthalate (DMP) was used as initiator .Chemical composition given below.

Peroxide content : 30%

Balance : 63% DMP, 4% MEK + Water

Fly ash- Unprocessed Concrete grade fly ash with d50 of approximate 15µm obtained from Wagners in Queensland, Australia.

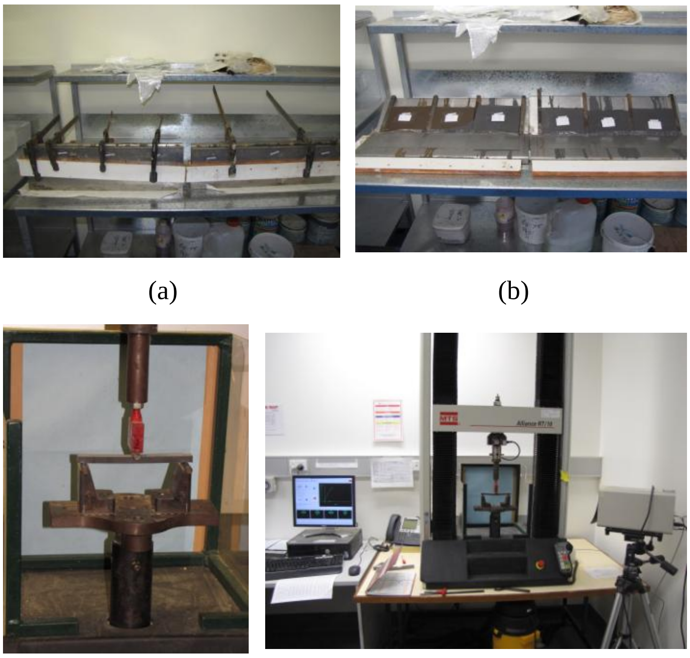
Sand – Fine dry sand with a bulk density of 1650kg/m3 and particle size smaller than 425µm.

2.2 *Testing*

Following tests were done to identify material properties.

Compression Testing- Compressive load capacity and modulus behaviour was investigated using uniaxial compression method. Testing was done in accordance to ASTM D 695 M-91 standard. Testing was undertaken using cylindrical specimens of a diameter of 50mm and a height of 120mm.

*Flexural Testin*g-Flexural behaviour was assessed using three point bending test accordance with ISO 178:1993. Specimens dimensions were l = 160mm, b = 16mm and h = 9mm. The support span was set at L= 144mm.Test setup arrangement is given in Figure 2.



(a) (b)

(c) (d)

Figure 2. Flexural Test : (a) & (b) samples preparation, (c) & (d) three point bending test apparatus.

Shrinkage Testing- A linear method was selected to assess the shrinkage in accordance with the ASTM standard D6289–98. This test method provides for the measurement of shrinkage of thermosetting plastics from their moulds both initially and after post-cure. A multiple cavity steel mould, shown in Figure 3, was fabricated with cavities to the dimensions specified for bars of:

Length = 127mm,
Width = 12.7mm, and
Depth = 12.7mm.

The pre-calculated masses of resin and filler for each volume fraction were combined manually and blended to ensure all of the filler was wet out and distributed evenly throughout the mix. The initiator was added and thoroughly mixed. Specimens were cast for filler volume fraction and allowed to cure at room temperature. The specimens were measured within 16 to 72 hours of casting to determine both linear and volumetric shrinkage.

Figure 3. Shrinkage testing mould

Gel Time- Trial mixes were prepared and temperature was recorded with respect to time. Then determined interval of time required for a colloidal solution to became semisolid jelly or gel. This time is known as gel time and allow for mixing and pumping operations.

3 EXPERIMENTAL RESULTS AND DISCUSSION

In this section, the material properties of the polymer base filler materials as evaluated from the experiments are reported and discussed. In most cases the results are the average of three tests.

3.1 *Physical properties*

Table 2 shows the densities of the test mixes. It is seen that the densities are considerably lower than that of Ordinary Portland Cement (OPC) mortars and concretes.

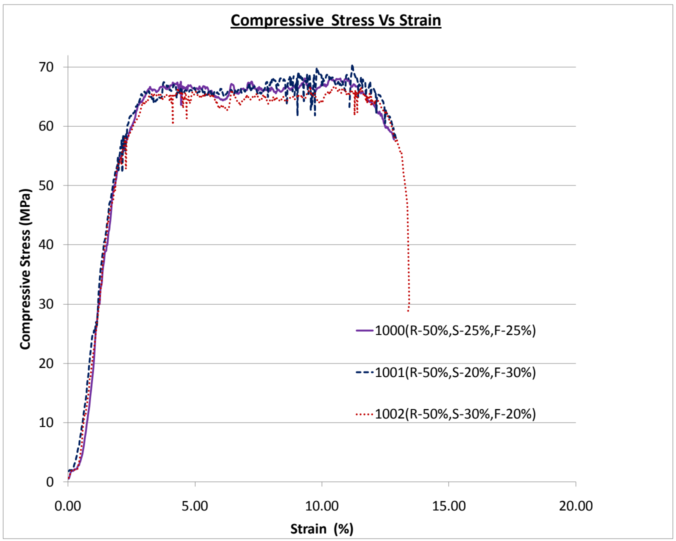
This test mixes was observed to be shrunk as it hardened. This phenomenon is similar to OPC concrete that shrinks as it hardens. The measured volumetric shrinkage of the test mixes were between 5% to 8%, depending on the mix proportions. Comparing samples 1003-1005 and 1006-1007, it is obvious that higher polymer content gives maximum linear shrinkage. This shrinkage property is important in this filler as it may lead to cracking due to confinement in FRP connector.

In this filler development, all the samples were mixed with 2.5% (weigh % of resin) of initiator. All three categories of mixes (1000-1002, 1003-1005 and 1000-1007), gel time proportionate to the

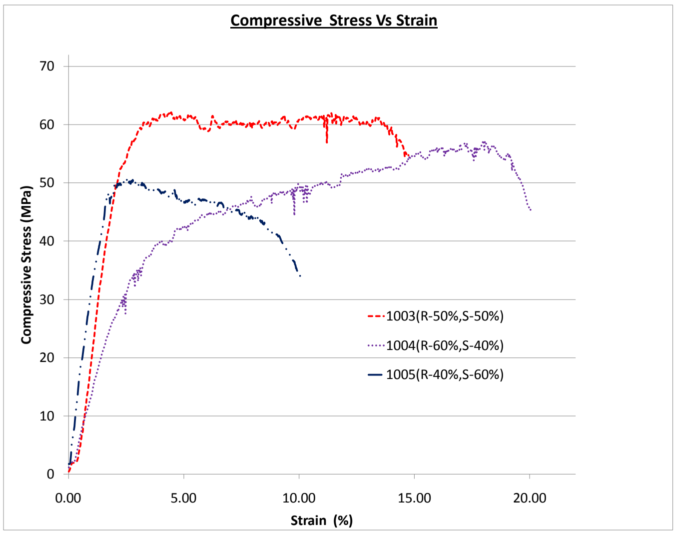
Table 2. Test results from compression test, shrinkage test and gel time test.

Sample Number	Gel time (min)	Compressive Capacity (MPa)	Compressive modulus (MPa)	Linear Shrinkage (%)	Volumetric Shrinkage (%)	Density (kg/m^3)
1000(R-50%, S-25%, F-25%)	65	68	3869.23	0.98	8	1451.83
1001(R-50%, S-20%, F-30%)	80	67	3357.14	0.73	6	1410.00
1002(R-50%, S-30%, F-20%)	60	68	3300.00	0.78	7	1443.85
1003(R-50%, S-50%)	75	63	3304.35	0.74	7	1514.06
1004(R-60%, S-40%)	40	45	1642.00	1.2	5	1468.69
1005(R-40%, S-60%)	180	50	2866.67	0.36	5	1660.88
1006(R-56%, F-44%)	40	58	2800.00	0.56	7	1288.05
1007(R-65%, F-35%)	20	43	2058.82	0.70	7	-
1008(R-45%, F-55%)	Difficult to mix – low percentage of resin					

percentage of fine material used. For example (samples 1002 and 1001), when fly ash amount change from 20% to 30%, gel time increases from 60 to 80 min. Therefore amount of fine material directly affects to the test mixes gel time.



(a)



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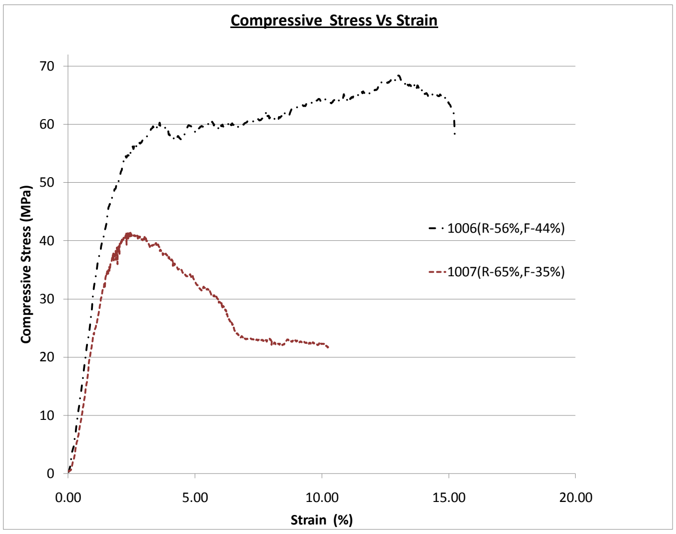

(c)

Figure 4. Compressive stress Vs strain graphs for trial mixes made out from (a) resin, sand and fly ash (b) resin and sand (c) resin and fly ash.

3.2 *Compressive strength*

All the samples achieved high mean compressive strength of more than 40MPa. In Figure 4(a) shows that sample numbers 1000, 1001 and 1002 have more than 60MPa compressive stresses with considerable uniform plastic region with more than 10% strain. Also above trial mixes have comparatively higher compressive modulus value more than 3000MPa. Here all samples used 50% resin by weight (resin: materials = 1:1).

But in figure 4(b) and 4(c) illustrate that trial samples have not uniform plastic regions except sample number 1005. This 1005 also used 50% resin by weight (resin: material = 1:1).

Therefore comparing Figure 4(a), 4(b) and 4(c), all the times nearly 50% resin (Resin: material =1:1 trial mixes) gives more uniform plastic region. Figure 5 shows typical compressive failure pattern for the polyester based fillers.

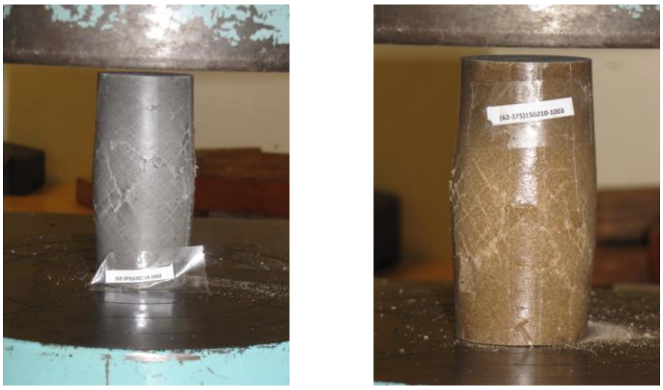

Figure 5. Typical compressive failure pattern for test cylinders

3.3 *Flexural strength*

Flexural test samples were selected based on compressive strength and modulus values. Here sample numbers 1004 and 1007 were not considered for flexural test because of low compressive modulus and strength.

Table 3 and Figure 6 show flexural values and flexural stress Vs strain graph.

Table 3. Flexural modulus

Sample Number	Flexural modulus (MPa)	Modulus of rupture (MPa)
1000(R-50%, S-25%, F-25%)	2828.37	21.19
1001(R-50%, S-20%, F-30%)	2550.31	20.61
1002(R-50%, S-30%, F-20%)	2558.85	20.30
1003(R-50%, S-50%)	2343.05	20.07
1005(R-40%, S-60%)	2818.91	15.19
1006(R-56%, F-44%)	1902.70	19.57

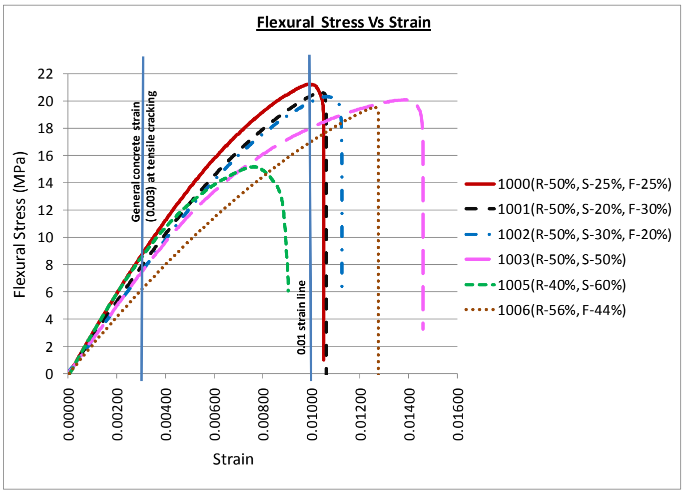

Figure 6. Flexural stress Vs strain graphs

According to Figure 6, all the samples except 1005 show good flexural stresses with more than 0.01 strains at failure, which is 3.3 times compare to that of reinforce concrete (0.003).

4 CONCLUSIONS

Based on experimental work of the tests presented in this paper, the following conclusions are drawn:

- More than 60MPa compressive strength can be achieve easily in the filler material development when polyester resin content vary from 40% to 60% (w/w) with fly ash and sand.
- Polyester base fillers having considerably low density compare to OPC concrete.
- The percentage of finer material used in the mixes directly affected to their gel time.
- Most polyester fillers having more than 10% compressive strain with plastic region. If polyester resin: Materials ratio 1:1, this plastic region becomes more uniform.
- Most of tested trial polyester fillers can be used in this connector, based on fine compressive and flexural stress, strain behavior compared to concrete. But shrinkage and gel time play important role to select appropriate mix configuration. Hence this preliminary study, sample 1001(R-50%, S-20%, F-30%) recommended as filler material based on less volumetric shrinkage and considerable gel time.

5 FUTURE WORK

The study on polyester based fillers with GFRP confinement under different loading conditions is currently underway at the University of Southern Queensland. The details of this investigation will be presented in forthcoming papers.

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